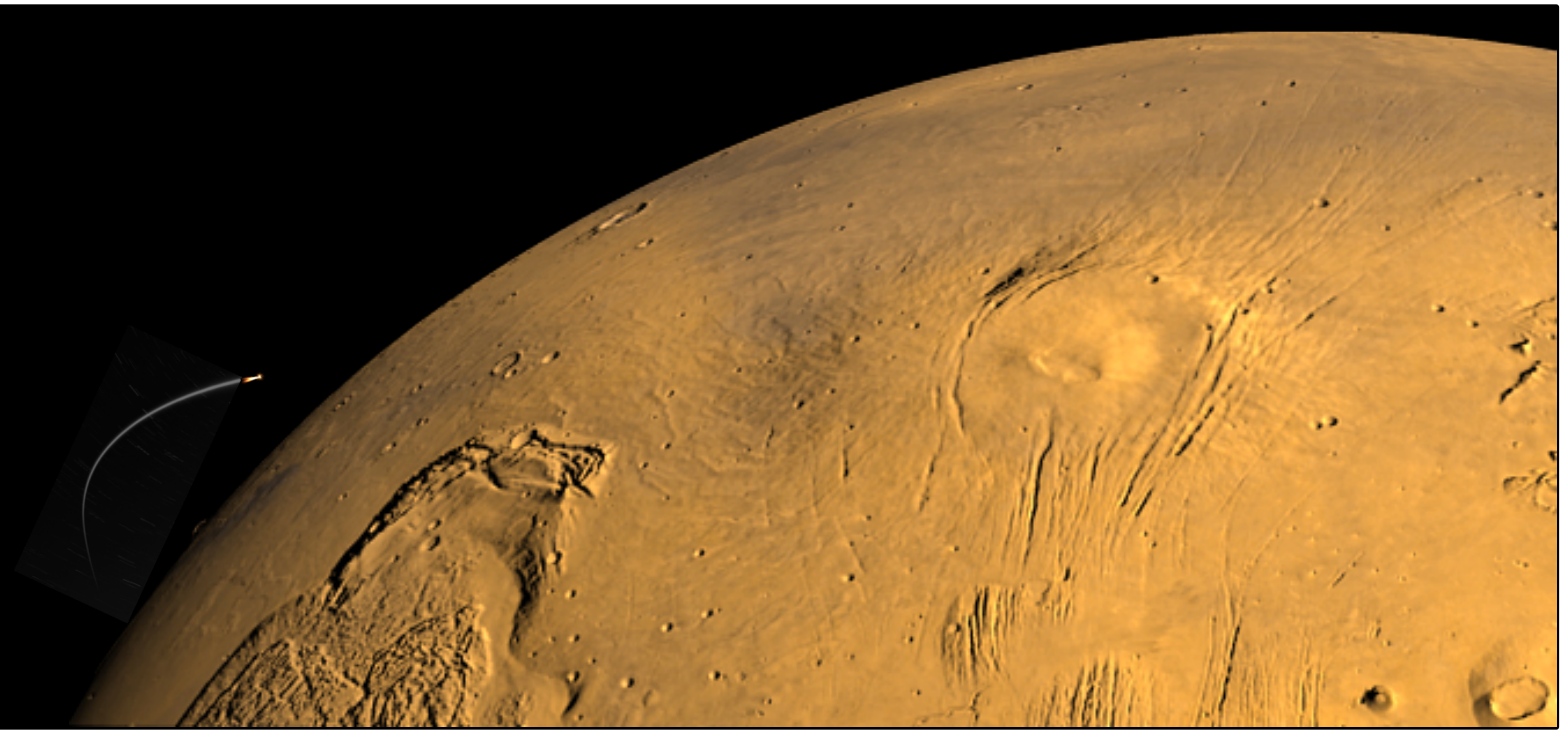
Mars Ascent Vehicle



Jet Propulsion Laboratory
California Institute of Technology

MARSHALL
SPACE FLIGHT CENTER

Hybrid Propulsion Technology Development for a Potential Near-Term Mars Ascent Vehicle

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7 March 2019

Pre-Desicional

Agenda

- Introduction
- Potential Hybrid Design
- Propellant Combination
- Full Scale Testing
- Hypergolic Ignition
- Liquid Injection Thrust Vector Control
- FY 19 Plan
- Summary

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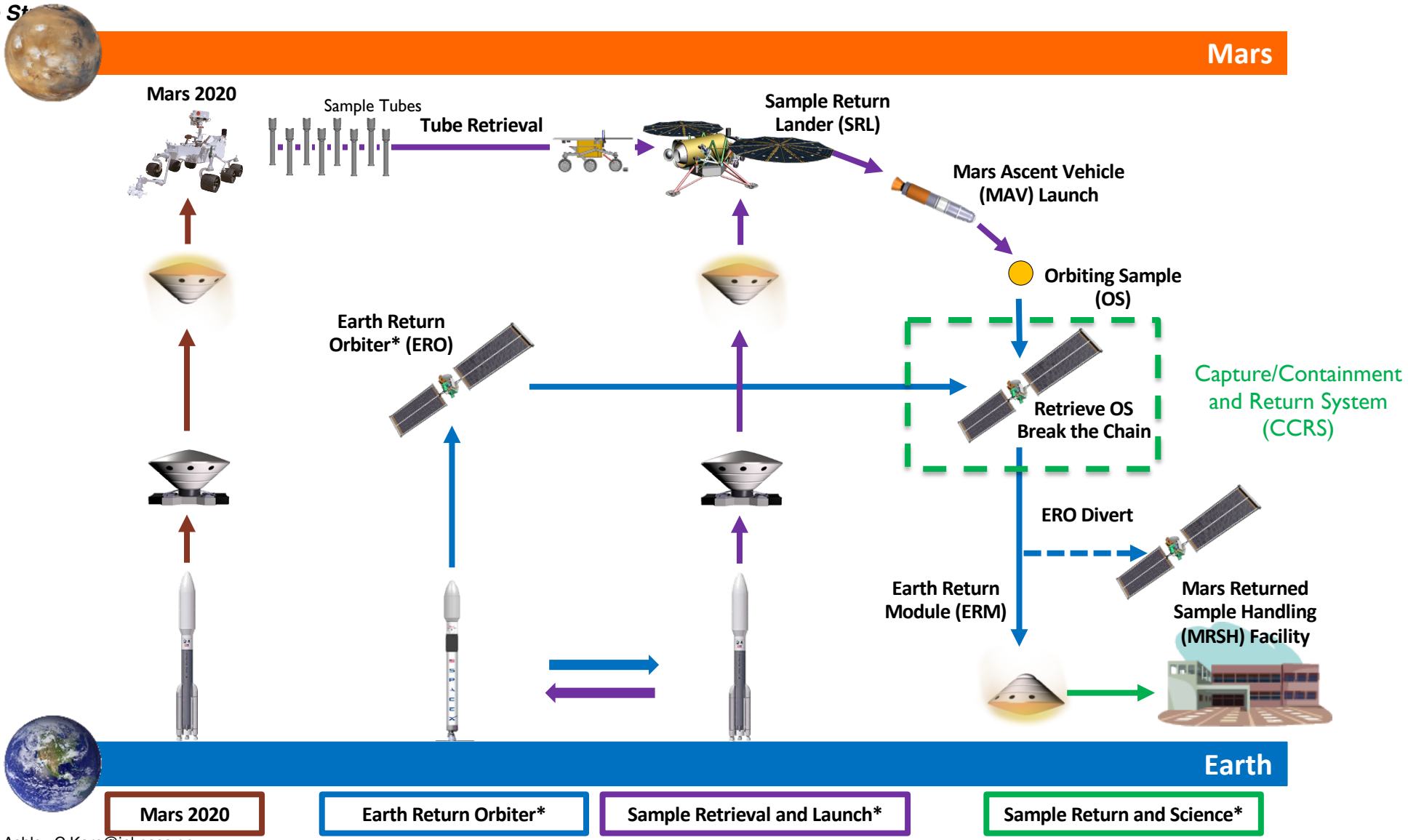
Mars Ascent Vehicle St

Potential Mars Sample Return Overview



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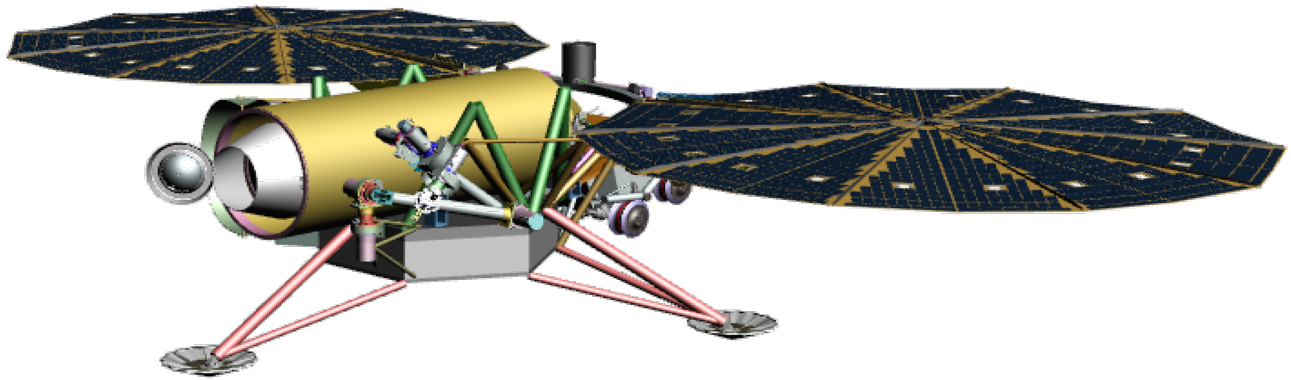
*Concepts under study

Potential Mars Sample Return

- A potential MSR campaign is being studied jointly by NASA and ESA for launch as early as 2026.
  - Technology development for a hybrid propulsion system
  - Vehicle level system studies of hybrid and solid propulsion options
- Sample Retrieval Lander
  - Studying a Propulsive Platform Lander and Skycrane Delivered Lander
  - Imposes mass and geometric constraints on the MAV



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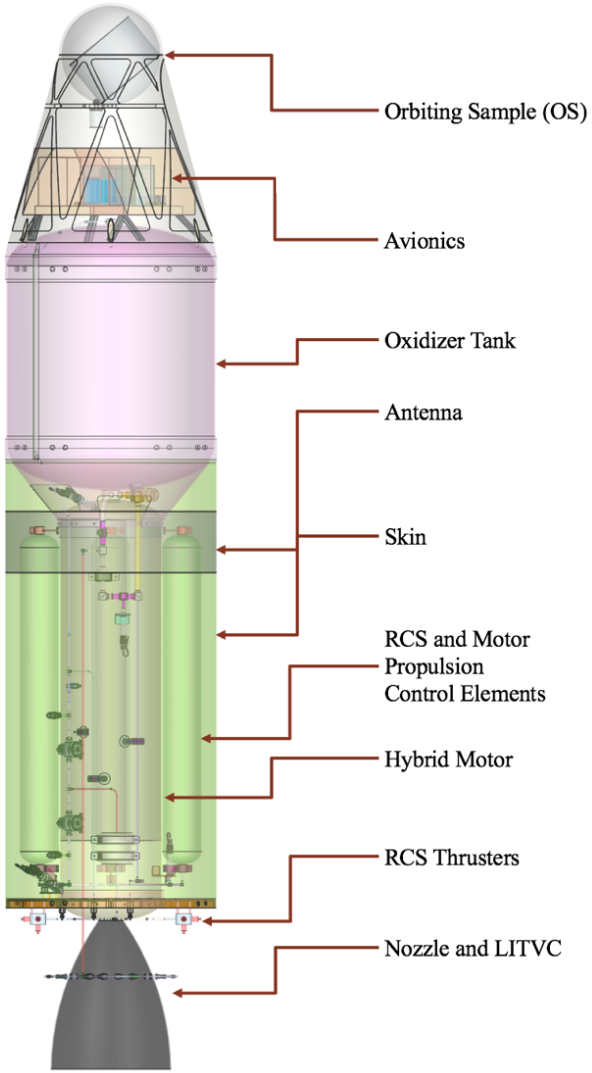
Potential Hybrid Design

- The main focus for the hybrid propulsion team has been technology development of the novel propellant combination. The design has matured along with this testing.
- Additionally, preliminary work on the Sample Retrieval Lander has started to drive mass and geometric constraints.
  - Mass: maximum of 400 kg GLOM for a payload of 12 kg.
  - Geometry: 2.8 m by 0.57 m



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Propellant Combination: Fuel

- SP7 is wax-based (higher melt temperature/viscosity than paraffin)
- *Residual stresses*
  - SP7 shrinks 15-20% in the liquid to solid phase transition
  - The wax cools from the outside inward, leaving residual stresses within the segment.
  - Grain Manufacture Process:
    - Cooling at ambient conditions lead to cracking
    - Controlled cooling rates (oven cooled) successful, but sensitive to minor changes
    - Annealing helped substantially for ambient cooled grains, under investigation for oven cooled.
  - Southern Research is carrying out material testing on SP7 to obtain material properties for modeling

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Propellant Combination: Oxidizer

- Mixed Oxides of Nitrogen (MON) is a common space storable oxidizer, but has not been used for a hybrid motor in the past.
  - Most existing propulsion systems use MON-0.5 to MON-25
  - Previous hybrid MAV concepts used MON-30 because of its low freezing point, <-80C.
    - The curve relating freezing temperature to the amount of NO in the mixture is very steep, with a difference of about 25 C between MON-25 and MON-30.
  - The current mission design indicates that the MAV and oxidizer could be kept above -40 C (the updated mission timeline does not require the MAV to be on Mars in winter)
  - A move to MON-25 was made in 2018 based on the new mission timeline and the availability of the oxidizer.

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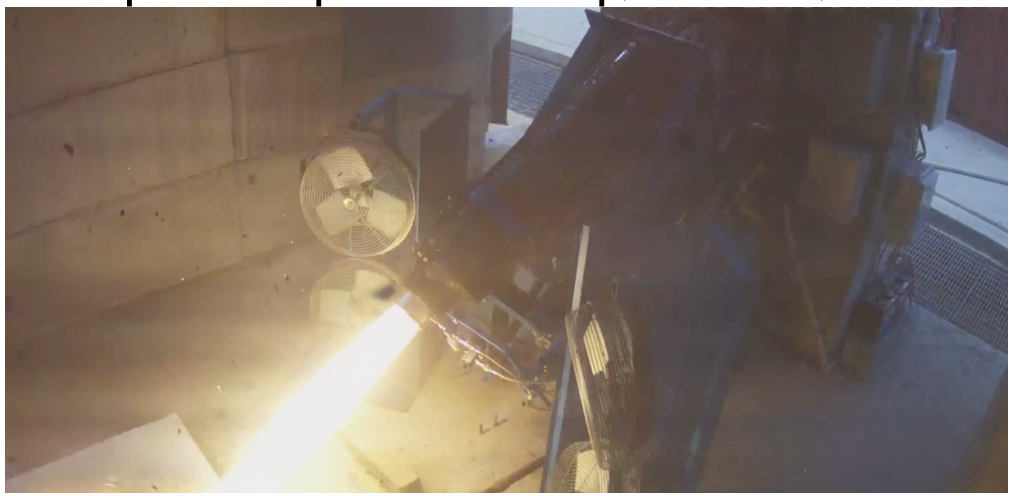
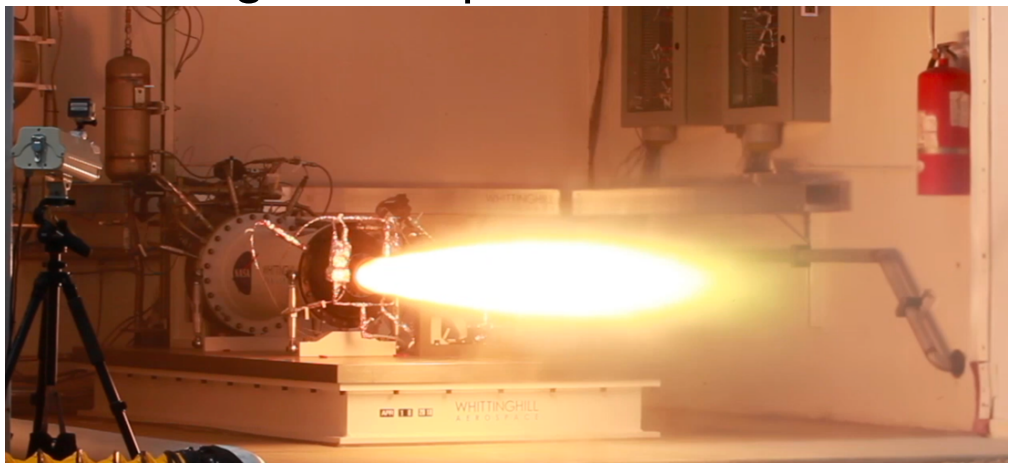
Full Scale Testing

- Two vendors have completed hybrid motor testing at full scale
  - Goals:
    - Mission-like burns: almost full mission duration test including a motor shutdown and restart without human intervention.
    - Performance: C* eff of 95% (achieved ~ 90%)
  - Concerns
    - Stability: using TEA/TEB to vaporize MON
    - Nozzle erosion
  - Testing with MON-3 (less expensive, easier to acquire and similar vapor pressures at atmospheric conditions to MON-25 at -20 C)

Space Propulsion Group, of Butte, MT



Whittinghill Aerospace, of Camarillo, CA



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Hypergolic Ignition

- Previous studies suggested that hypergolic ignition would be the lightest mass option for MAV
- Two methods of hypergolic ignition are currently being considered.
  - Liquid: Hypergolic liquid with the MON oxidizer
    - At the time of the paper, Triethyl Aluminum and Triethyl Borane (TEA/TEB) was being considered.
    - Commonly used (with oxygen) in rocket applications
    - Purdue completed a drop test with N_2O_4 that indicated it is hypergolic with TEA
    - Alternatives are now being pursued.
  - Solid: Solid materials are added to the hybrid fuel grain that are hypergolic with MON.

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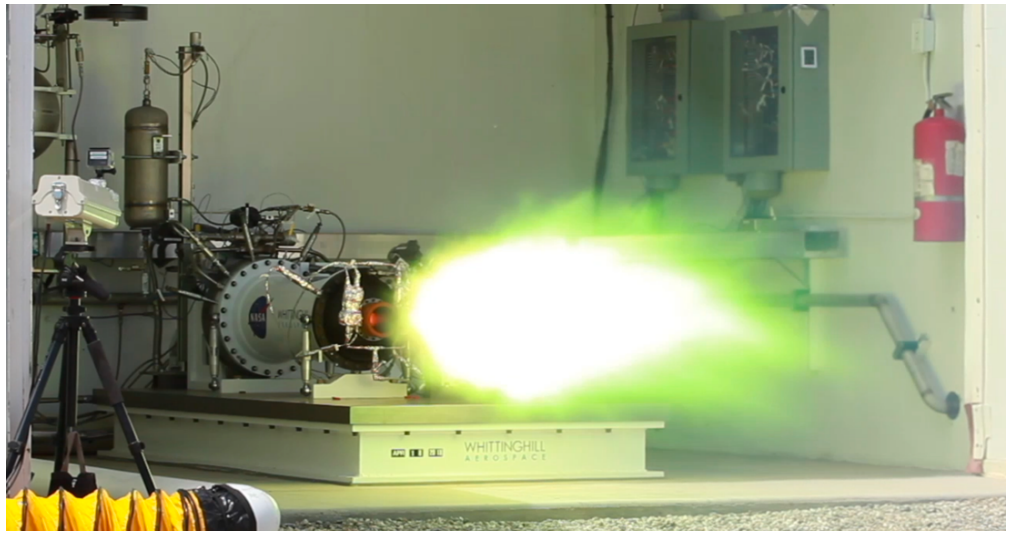
TEA/TEB

- *TEA/TEB* is currently being used with a small amount of GOx to ignite the motor and maintain stable combustion throughout the burn (vaporize the MON)
- Disadvantages:
  - The TEA/TEB system accounts for nearly 20% of the total component count in the feed system.
  - Safety considerations of carrying a hypergolic liquid
  - Performance at low temperatures may not be sufficient
  - Preliminary testing indicates that TEA/TEB is not hypergolic with MON



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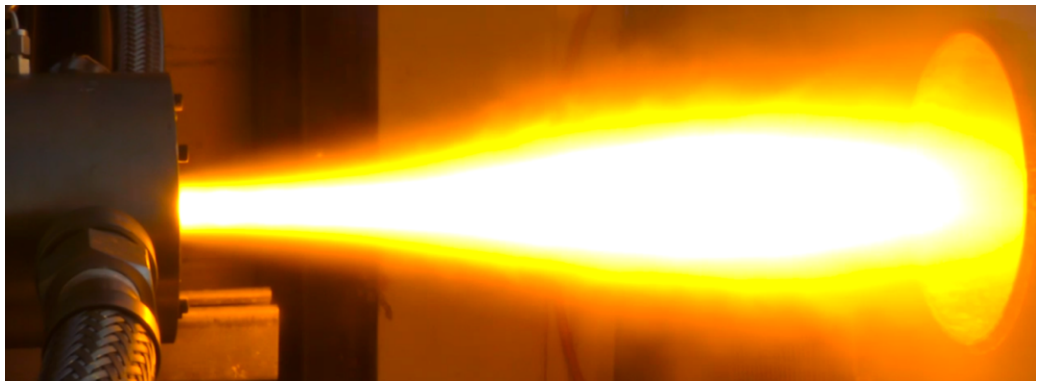
Solid Hypergolic Additives

- Subscale hotfire testing (2 inch scale) at Purdue confirmed the performance of several solid hypergolic options using different amide formulations and MON.
- Solid hypergolic materials simplify the design by not requiring additional tanks/plumbing
- Unique processing steps were developed by Purdue to incorporate the material into SP7.
- The main disadvantage of this option is the additive's sensitivity to moisture, complicating handling of the otherwise inert motor.



2" motor test at Purdue

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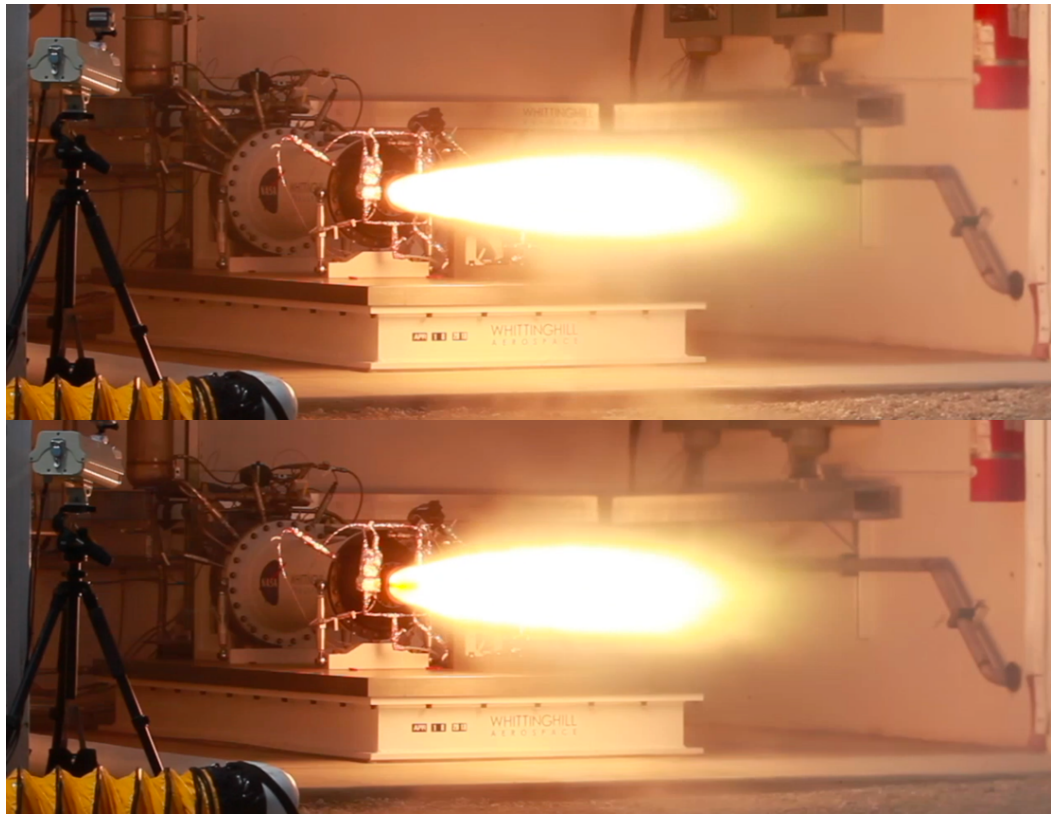
Liquid Injection Thrust Vector Control

- LITVC was initially selected because it was the lowest mass option and only small deflections (1-2°) were required.
- Design: Four pairs (90° around the nozzle)
  - One valve would provide sufficient flow for a ±1° deflection and both valves would provide ±2°.
  - Currently modifying a light weight, fast acting valve for MON service.
- LITVC testing has been completed under Earth ambient pressure and temperatures.
  - Different X/L, but data will anchor modeling.
  - Testing this summer/fall will confirm vacuum performance.



LITVC Testing at Earth Ambient Pressure

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FY19 and Future Work (1/2)

- The goal of this technology development program is to have demonstrated the major milestones required for a hybrid MAV design that closes under the current assumptions for Mars Sample Return by the end of summer 2019.
- The highlight of this effort will be testing of a thermal cycled, full-scale hybrid motor under relevant (low pressure and cold) conditions at White Sands.
  - Up to five additional hotfire tests are planned to prepare for the WSTF test.
    - Three tests focus on motor development for the wax-based fuel and MON-25 oxidizer and achieving performance and burn time goals. (Whittinghill)
    - Two tests with the goal of demonstrating a light weight motor case under relevant thermal conditions (SPG)
    - Multiple subscale tests will determine the regression rate of a slightly modified SP7 with the goal of achieving an approximately 15% reduction.

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FY19 and Future Work (2/2)

- Purdue will test hypergolic ignition of SP7 with solid additives and MON-25 under low pressure conditions this year.
  - Full-scale testing will continue to use a liquid hypergol for ignition this year
  - The potential for adding solid additive to a hybrid MAV will be evaluated and a decision should be made by the end of 2019.
- A qualification program for a hybrid motor will continue to be refined.
- MSFC will be leading a study to design complete concepts for both a hybrid and solid MAV vehicle
  - This study will work closely with the MSR and SRL studies being led by JPL to make sure the MAV concepts fit within the higher level architectural constraints.

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Summary

- A technology development program is underway to determine feasibility of the hybrid option for a potential Mars Ascent Vehicle as part of a potential robotic Mars Sample Return Campaign.
- Substantial strides have been taken in the propulsion system development.
  - Full scale hotfire testing has been completed at two vendors and the development is ongoing with both vendors joining their efforts.
  - Hypergolic ignition has been researched and demonstrated using solid additives and liquid options are being considered.
- The potential design is continually updated based on the developments of the development program.
- The goal is to present a design that closes by the end of summer 2019.

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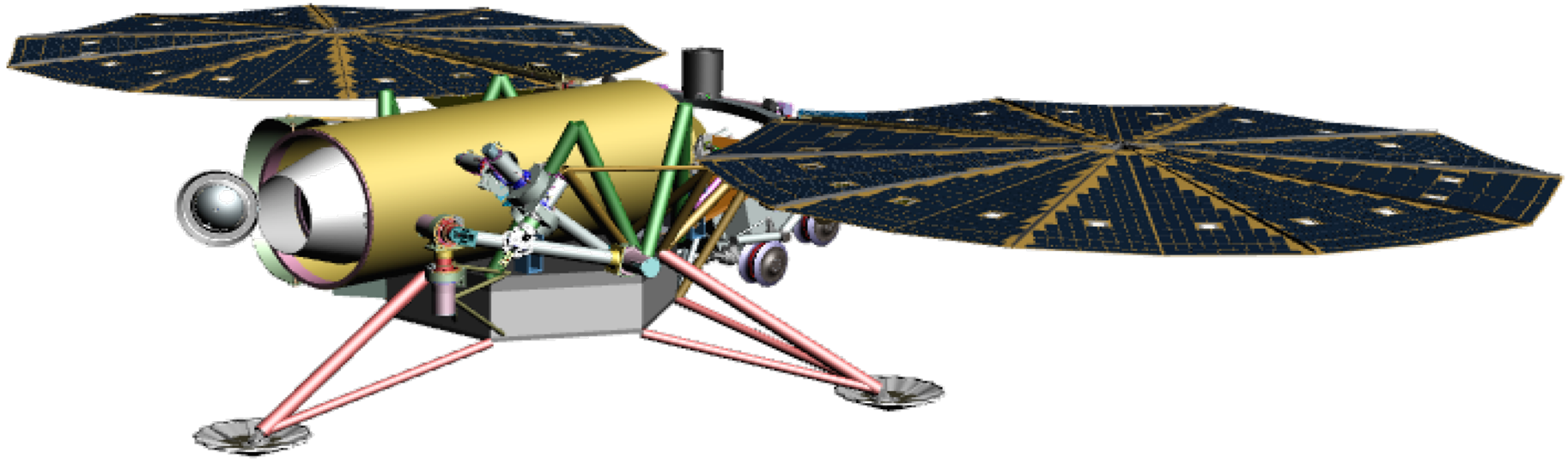
Questions?



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